

Advances in Additive Manufacturing of Materials: Current status and emerging opportunities

Prof. Bikramjit Basu

Materials Research Center, Indian Institute of Science, Bangalore

Lecture 25

Welcome back to this NPTEL lecture and this time it is with great pleasure that we introduce one speaker from industry, Dr. Vishwas Puttige. Dr. Vishwas Puttige completed his Bachelor of Engineering in Electronics and Communication from PESIT, Bangalore in 2003. He completed his Master of Engineering in Systems Engineering from the Australian National University in 2004. And subsequently, he finished his PhD in Automation and Adaptive Control Systems from University of New South Wales in Australia in 2008.

during this course, he also worked as a research associate at the School of Aerospace and Mechanical Engineering. In 2008, Dr. Vishwas Puttige joined the R&D Department of manufacturing systems limited. He was also involved in business development general management segments at AMS.

Sometimes later Dr. Vishwas took the charge as the business head of a new company that he was involved from the beginning and the name of this company is Amace Solutions. this company provides product related solutions in metal additive manufacturing. Under his leadership, this company has developed one of India's first industrial grade metal additive manufacturing machines with many patented features on it. This company has also received National Startup Award in 2022 from the Government of India.

In the 3D printing category, currently Dr. Vishwas Puttige is the Director and CEO of Amace Solutions. He also has been a TEDx speaker and ISO 9001 lead auditor for quality management systems and internal auditor for AS9100D aerospace standard and is also a black belt in Lean Six Sigma implementation processes. He is going to take two lectures and then title of his lecture is additive manufacturing of materials with a clear focus on applications, solutions and future perspective. Now I will request Dr.

Vishwas Puttige to deliver his two invited lectures as part of this NPTEL course. And I am sure you will see that there is a strong relevance of his lectures particularly as I have already covered all the process science related to the selected laser melting and directed energy deposition processes which are two major processes which are involved in the metal 3D printing. Thank you. Hello there. My name is Vishwas Puttige.

Welcome to this lecture. I come from a company called Amace Solutions Private Limited. We are a part of AS Micromatic Group, one of the largest CNC machine manufacturing group in the country. My topic today is going to be additive manufacturing of materials, applications, solutions and a future perspective. So let us move on to the lecture.

Now if you see the topics that we are going to be covering today involves generic process flow of additive manufacturing in the industry. Need and relevance of this why is it important we will be looking at different engineering components, we will be looking at some applications and case studies, current challenges in additive manufacturing, future of additive manufacturing and solutions for these challenges. Some of the keywords that we are going to be talking about are additive manufacturing, AM, metal 3D printing, aerospace component, medical implants, mass customization, cobalt chrome, titanium alloy and a few others. I will not dwell into the process of additive manufacturing you have already learned that in the previous sessions. this is a generic process flow for laser based powder bed fusion the PBF technology which you have learned earlier.

in general the process of additive manufacturing for the powder bed fusion follows this flow diagram. As you can see we start with a CAD data you are all aware of how we use the CAD data for our applications. We need 3D models either in the generic format or in universal neutral format such as STL which is the input for the

software that we use. Now one of the key aspects of it is nesting this entire thing into the build volume as you can see in the first image here that is shown. The part that has to be 3D printed is nested what we mean by nesting is ensuring that is well captured within the frame of the machine or the process in which you are printing.

You can see one of the key aspects is support generation. supports are a necessary evil of the process you need to support metal parts inside the build because they cannot be printed without being supported from the bottom. these are material these are actually parts which are much lighter in density and they are used to provide two applications one is to provide physical support and second is to dissipate the heat from the melt area melt pool area. you can see that in the tensile coupon that is shown here we have some supports. The component that has been shown here actually is a supportless part, it does not involve any supports, it does not have any support but otherwise these parts are normally supported.

This anchors the part strongly onto the base plate on which you are going to be printing. So that part of it is taken care by the software which does the part orientation and support generation. Once we have that clear once we know the methodology of nesting it and once we have had that all included inside the volume then we go about preparing the job or the job file wherein we identify various aspects including the parameters that are required. hatching strategy that is required the layer thickness the material every aspect of it is identified and then that is fed into the machine to ensure we get the right part and the part of the correct quality and finish in the first course. this is getting the job file ready so that part of it is taken care by the job preparation process.

Now once we have this ready we feed the job file into the machine. We do the additive manufacturing process we do it layer by layer as you all understand the powder bed fusion works in the method where you spread powder on a platform and layer by layer from the bottom up we start fusing them and here the powder gets melted to its melting point. it fuses to the previous layer and forms a very strong bond and the strengths are as strong as forging components so that is what is taken care by the additive manufacturing as a printing process. Once we have printed we finish the component we take it to post processing in certain cases it may involve some heat treatment just to relieve stresses or if the application calls for having maybe a hardening process we go through the post processing with a heat treatment. Then you separate the part out do any surface finishing process either by glass bead blasting or shot blasting or other finishing processes to get the part ready and once you have the part finished you ensure that it meets the quality requirement either by non-destructive processes you can see you have.

dye penetrant test, you have CT scanning, you have X-rays and many other quality inspection processes to ensure we have the part meeting the end application requirement. So, as you can see in the flow here, this is the job preparation. process of printing this is the software that shows you that and then finally you have the end part ready the finished part in the in its ready finished state. This is how the generic process flow of the entire metal 3D printing follows for a laser powder bed fusion technology you could have few pre processes and a few other post processes attached to this based on the specific application in certain cases we also involve reverse engineering where we create the 3D file itself from an existing part where you scan the part and get the 3D model ready itself and in certain other cases we also may have some machining or few other aspects that may be involved from a post processing perspective. Now why is there a need for additive manufacturing? We will take a step back and see what is the actual need.

here are some statistics which shows that in India a three wheeler is being produced every second. this is a line of maybe a Bajaj auto or another three wheeler just depicting this specific statistic. where every 24 seconds there is a three wheeler that is coming out. You can see that being made in a flow line assembly. Similarly, a four wheeler, a car is getting produced every 8 second.

Then we have a motorcycle being produced every 2.2 second. And then finally you have someone like Apple making 10 iPhones every second. So this is just giving you a sure size in terms of what is the volume of a generic industry where we stand today. These numbers may be up or down but the point that we are trying to

drive here is we live in a very very high volume consuming base from an industry perspective.

Now what is happening in terms of this volume? What is changing? This has been there forever. What is new here? Now, the buyers are getting more demanding so what used to be a long gestation period for product development in many cases earlier products would get developed a cycle of about 5 to 8 years be it a car or a motorcycle they would not undergo revision in design or modification to the existing product would not happen for many years. But now people are demanding it much, much faster. They want it now. They want things to be seen now.

So the demand is increasing. the changing scenario is everyone wants something new, something next. manufacturers have to step up to this. the varieties are increasing. if you actually see earlier one specific variety would get manufactured in much higher volumes, but now that is shrinking, but varieties are increasing.

someone a mobile phone manufacturer has to make something every year, a car manufacturer has to modify his car every second year maybe. Similarly, a motorcycle manufacturer has to launch something every year or every alternate year. This is the challenge that is being seen in the industry for which there is one of the techniques or technologies that is supporting this very strongly is additive manufacturing where you are able to develop products much faster, their prototyping is much faster, rapid prototyping becomes much easier and you are able to launch it to the market much sooner than what it used to be earlier. Similarly, every aspect of it not only for prototyping but batch production and eventually even the mass production is very well supported by 3D printing. It is not the only technology but one of the technologies which is supporting this growing demand from the industry.

Now to meet this where is this going to lead to? So what some of the manufacturers are working on is distributed manufacturing. This is one of the future trends that is there where we have one focal company where you have multiple local companies which are attached to that. the manufacturer can dynamically distribute the load based on the current condition. So earlier the lead times used to be much longer for a specific part to be produced and supplied but here the newer trends are where you are able to meet these demands much faster by distributing the whole manufacturing cycle chain where you have local companies based on dynamic availability or the equipment availability manufacturers which are focal companies are able to source it from individual local companies it could be A, B or C based on the current condition of available load on them. this is what is going to grow going ahead.

this is one of the methodologies called distributed manufacturing which is catering to the growing demand of the customer. So this is where you have material that can be in real time allocated raw materials and the production can be planned and then sourced. on a dynamic basis. Another popular technology that is strongly coming up is mass customization wherein we have customer and the customer's demand as I said is becoming more and more customized if you see manufacturers are offering customized solutions to every end user. Be it automotive is one of the last ones to adopt this but in every other sectors you will see that be it in sports equipment or be it engineering components other aspects where the varieties are increasing and the volumes are shrinking so to meet this you have mass customization so one of the most industry which is adopted this well is medical sector wherein you have your hearing aids are completely today being 3D printed which are customized which means in a given set of volume you have one product that one part that is being made for every individual customer and customer but they are all mass produced.

customized parts being mass produced is what this is called what is called as mass customization. you have product design and build to order at a factory that is happening on a continuous basis but they are all built to order. which is what is the customization part but since the volumes are high. this is a technology which is helping that. this is one technology additive manufacturing which is supporting mass customization very strongly.

that is what is adding or demonstrating one of the future trends which is mass customization. Now a

demonstration is your eye wears today are being mass produced by some of the manufacturers where volumes shrinking to as small as 1 where earlier it used to be minimum order quantity of X numbers but today it is shrinking all the way to 1. Because the user is becoming more and more demanding and choosy, manufacturers like eye wears are doing this where people can go try it on in a digital frame where they can see how they look and then decide what design suits them and that gets 3D printed and offered to the end customer. more specific customized parts is what we are seeing. today we all understand when we say manufacturing one of the biggest industry is automobile.

So one car manufacturer has already started doing this for some of the softer aspects. We all know this car Mini Cooper. Mini has launched 3D printed personalized upgrades where you can choose some of the cosmetic parts like these the inner touch and feel aspects of it are being 3D printed. the day is not too far when we will be able to choose what aspect of it being a steering wheel maybe the seats maybe something else that could be customized and one technology that is supporting this very well is the metal or is a 3D printing route. when it comes to metal again very similar you get into get to choose what aspect of it that can be 3D printed comfortably.

Even in India we have people from eyewear manufacturers who are exploring this as a possibility where higher volumes can be produced in much shorter time but they are all customized for end user. So that was about one of the other new trends that is there from a future perspective. Now what is happening from some of the other recent advancements we have been hearing a lot about artificial intelligence being used in 3D printing or in generic in all industries. one of the areas that additive also is adopting to is artificial intelligence. Where is it relevant? we have AI being used for creating better 3D printable models, we have a good prediction model that is coming up to tell what design would be more suitable for printing and how AI is supporting in generating hundreds of designs and in a matter of very short time there are programs which are able to churn out different design combinations and finally they can go they can be put through some design simulation to finally say what would be the most suitable one.

That way some of the human intelligence has been captured and there are software solution providers where they are providing either light weighted parts as you can see here in a much faster way through a process called as generative design where hundreds of design can be produced in a very short time all using some past experiential data which is fed into AI as a form of a prediction model. Something similar that is happening is to improve printing process, so when we say printing process today every manufacturing process has failures attached to it, so some of the earlier defects can be fed in and then there are manufacturers today who are exploring or software providers who are working on developing these kind of advanced tools where all the past experiential data in terms of the process is fed in to ensure that we get first time right in the printing process. once we use this, this helps in minimizing the losses or defects because of any war pages or other defects that happened during the printing process and the rejections are brought down to minimum. So that is again another useful application of AI in the printing process. In AI we also have machine learning which is allowing problems to be detected and quality can be controlled better.

So as I said not only from the physical damage or issue that can come instead people are getting even further where the melt pool is being monitored there are people working on methodologies of predicting a potential crack or a potential porosity that could come up in the whole printed printing process to get much better quality parts at the end of it. because currently bulk of the inspection or quality control methods are all as a post printing aspect that is available which means we print the part we manufacture it and then go back to see what has happened to the part and how we could have corrected it. instead of doing it as a post printing process and inline process where people are exploring real time monitoring and getting the quality much better on the fly. So this is another interesting trend that is coming up which will help immensely in the manufacturing process. Now we will look at some of the case studies, we look at different case studies that are there in 3D printing which is going to give you a diversified perspective as in how those technologies supporting medical, aerospace, automotive, tooling and general engineering sectors.

So when it comes to medical we have surgical assist fixtures tools that are being produced using 3D printing. Today doctors are able to create the entire situation entire environment of how the patients inside the body is in the entire data can be captured and that can be recreated using printing polymer printing. and then we can penetrate inside in onto that polymer part and then see how the same effect is available so that the any surprises that may arise during the actual surgery can be avoided. So the entire surgery process can be minimized to just enough so that you do not end up wasting a person's time during the patient being cut open. that is one area a lot of healthcare equipment parts are being 3D printed.

A lot of medical implants are being 3D printed both customized one and generic implants are being 3D printed. When it comes to aerospace a lot of lightweight structures are being done in minimum time with minimum machining required. So if you know in aerospace as a term called as buy to fly ratio which means in conventional process a 10 kilogram input part could get scooped out and finally when it becomes ready to fly it could be as low as maybe 500 grams. So, about 9.5 kilograms of material is wasted all that can be minimized by converting into 3D printing where just enough material is used to produce that part and then finish that part for the end application.

So, a lot of scrap is reduced and it is made more suitable for 3D printing. Again, coming to automotive prototyping is one of the largest application is being used for the past many many years and even in India this is very well adopted we will look at some of the case. When we say tooling we are referring to both multiple ways one of them is plastic injection molding wherein some of the tooling inserts are being 3D printed we will look at some of the cases and another one is where we have die casting dies which are being 3D printed using metal printing process. And finally a lot of other general engineering subjects like your turbo energy, oil and gas industry, many other prototypes for complex geometries and assemblies are being 3D printed both for energy sector and other engineering sectors. So these are in general summary of the market segments that are there.

We will quickly look at some of these interesting case studies. As I said from a automotive perspective these are interesting parts such as automotive component for one of the Indian automotive manufacturers where they had to launch this product and this had to be done in a very short time. So you can see that the part this is the actual part and these are the supports as I explained earlier. So the supports are basically parts which are supporting them physically and they are also there to reduce the heat that is generated all these lines are the supports that are there.

These can be easily removed. either through a manual process or a machine can be used to remove that. So this is one of the automotive components printed in aluminum alloy. Here again the whole process was less than 10 days to manufacture this which otherwise would have taken many weeks to manufacture it using the conventional process. Again another interesting case for an electric vehicle this is something that we manufactured for one of the startups here from India where a lot of load bearing components like these structural parts where components had heavy weight coming on them were printed and also some of the peripheral parts which were more from an aesthetic perspective which were 3D printed again in aluminum for this automobile company called as Orha energies. So the interesting aspect was anything all that you see in this green color and some of these parts were all 3D printed more than 70% of the bikes parts were 3D printed by us in a span of less than 12 days we printed about 3 motorcycles 2 of them went all around the country.

setting a Guinness record of one of the only electric vehicle manufacturer of electric vehicle which went on to ride about 14000 kilometers in following this Bharat Mala tour. So this was done on our machine by our company. So more interesting cases where not only was it 3D printed but also some design for additive manufacturing was used here you can see topology optimization or light weighting was adopted here we had that design flexibility. So you can see some of the cases where weight was reduced though to a smaller extent but the advantage that 3D printing gives you is you can try out different varieties you can try out multiple of these without having to.

invest heavily on the manufacturing process. So that is the advantage that 3D printing allows you to do. So here

this was conventionally being done through a block machining whereas with 3D printing it was done much faster and much better and also lighter. So this is an energy generation case study where these are hollow struts for a power generation example. Now here the conventional process was taking a solid block or a forged component and a lot of machining was involved but the challenge was to get the hollowness inside.

Here it is actually hollow structure inside what you see. Now where they have cooling lines going through. It is actually a production part for an engine which is converted for power generation. here each of these struts are actually being used for the application. Now this is being done by one of the manufacturers on a continuous basis. This is an annual order as you can see here it is a serial production application that is there which is using a material called as Inconel 718.

It is a nickel based alloy, it can take high energy, high temperature. in this case I think the temperature goes all the way up to about 1200 degrees. manufacturing this is a big challenge in a conventional process, but in 3D printing this was done with sufficient ease. A lot of simulation went into doing this and advantage is manufacturing time and getting the challenges in terms of the hollowness reduced. that was a big advantage that was seen in this whole manufacturing process.

multiple of them are formed I mean are used in one assembly and multiple of these assemblies are used in the whole manufacturing process. like this in energy and aerospace application , 3D printing is being used extensively. This is a lattice structure that was done for the space organization in India ISRO. here you can see the part is a much larger size one conventionally very challenging to make because of the light weighting that is required. you can see the entire lattice structure that was done on the part.

manufacturing this is going to be very challenging conventionally, but using 3D printing the advantage it gives is making it lightweight any design any concept can be manufactured with sufficient ease. You can see here this entire support was used to place the part diagonally and produce them in this shape. In this case the entire volume the machine build volume is much smaller but because of the diagonal shape we were able to achieve the large size of 524 millimeter in this. the printing time was less than 2 days which otherwise would have taken much longer had it been the conventional manufacturing route. this is a light weighted space satellite bracket that was manufactured.

these are different thruster components we have manufactured them in different sizes and shapes these are basically the last stage of a rocket engine where the gases come out. you can see the simulation or the animation shown here. Now, invariably they again go for very high temperatures. these have been manufactured for small size micro thrusters to normal size ones for rocket engines. from a smaller size perspective these are normally used for your satellite correction to meet the orientation requirements.

these are after deployment they put to use in the space. many such printed parts have been put into space from space application perspective. this is an aesthetic part that was done for Chandrayaan project as you can see Chandrayaan had 3 different paths one was an orbiter which went around the moon second was a lander which was there to collect some information and the third part was the Pragyan which is the rover. And on the rover it had multiple wheels and on the last two wheels they had the ISRO logo on one wheel and India logo on the other wheel. India emblem which you can see which was imprinted on the moon surface was 3D printed by us.

we proudly say the India signature on the moon was 3D printed by Amace. this is an interesting case where a milling cutter where you have these heavy milling process which happens. the milling cutter was 3D printed. So normally in milling application you have these cooling channels which are required conventionally made very challenging to get those lines but because of the circular cooling channels this becomes much easier to manufacture. you can see these cooling channels which are 3D printed again here also. all of these, these are printed in the material called as maraging steel after heat treatment it goes to about 54 HRC and gives you very strong hardness application and done in a very short time.

The advantage is the design itself which is very challenging to do otherwise and gives you much better efficiency during the cutting process. this is another interesting engineering application. Coming to medical so this is a knee implant as you can see this is printed in a material called cobalt chrome which is a medically approved material and this is printed and then finished to give this kind of surface finish. this goes in this is used both in two varieties one is a generic implant which is of a standard size second is a custom implant which is taken based on a specific person's size and shape.

and it is designed and manufactured to suit the specific patient. here again the advantage is reducing lead time and it could be patient specific which is customization for this specific patient. this is printed and then finished for medical application. coming to the die manufacturing one of the advantages of 3D printing also offers is hybrid printing where we can take an existing plate and print on top of it with cooling channels. the advantage that this technology gives is we can have such curvilinear or circular cooling channels which gives you much better cooling efficiency. this is largely used in plastic injection molding in this case this is a battery case for an automotive application.

you can see this bottom part is the conventionally taken plate in H13 and the top part is printed using maraging steel. this is what we call as hybrid printing where after printing you can machine the part and get the final finish as required. another interesting hybrid printed part as you can see here which is taken as a conventional part and then printed on top. this is the only part that is printed here you can see this hole is made conventionally and this vertical hole which comes and joins this hole is made vertically so they have cooling channel water going through this comes straight up but after that on top you have a circular cooling channel which is shown in this specific area. this is also done in maraging steel advantage is the heat affected zone in this area gives uniform cooling.

So you are able to improve the productivity by about 30 to 40% when you are using something like a conformal cooling here. This is for a die casting application where conventionally there were higher rejections because of blow holes that are there in the part. Now because of this spiraling cooling channel this gives you much better performance of the die casting. You are able to eject and get the part ready much faster.

In your gravity die casting you get much better productivity in the whole process. again here cycle time is reduced and rejections are reduced. there is a much bigger advantage here. These are interesting cases where you have 3D printing of sipes. These are basically what are giving this zigzag threads on the die of a tire industry.

you can see these are manufactured in high volumes today. Conventionally they were all being done through a stamping process but the advantage of 3D printing is it can be made in multiple shapes and sizes and some of these holes which are very difficult to manufacture conventionally are done easily using 3D printing. This is again done in this material called maraging steel or 18Ni300. It gives you the advantage of one bringing the whole manufacturing time down and there is no minimum order quantity. very low volumes also can be produced without any investment towards the manufacturability of this whole thing.

this is from a mold industry to an automotive application. those were the topics that we have seen now in terms of applications and case studies that are there. in the next lecture we will look at the other aspects of this topic here. Thank you.